

The Implications of Image Collimation for Flight Simulator Training

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There is some question as to whether non-collimated (i.e., real) imagery viewed at one meter or less provides sufficiently realistic visual cues to support out-the-window flight simulator training. As a first step toward answering this question, we have obtained perceived size and velocity estimates using both simple stimuli in a controlled laboratory setting and full simulator imagery in an apparatus consisting of optically combined collimated and real-image displays. In the size study it was found that real imagery appeared 15-30% smaller than collimated imagery. In the velocity studies, the laboratory data showed that the perceived velocity of real imagery was less than that of collimated imagery. No perceived velocity effects were found with the simulator imagery. Results support the position that for training tasks requiring accurate perception of spatial and temporal aspects of the simulated visual environment, misperceptions of size, but not velocity, need to be considered when real-image displays are used.

INTRODUCTION

Traditional visual displays used for high-fidelity flight simulators incorporate optics or large projection domes to effectively collimate the imagery to near optical infinity. They are used in an attempt to provide the visual cues likely to be present in the real flying environment. In addition, collimated displays are required by the Federal Aviation Administration for certification of all level C and D flight simulators (U.S. Department of Transportation, 1991). However, collimated displays produce a significant amount of light loss, image distortion, and field-of-view restrictions. These limitations, combined with the high cost and large size of these displays, make them unsuitable for low-cost, deployable, military applications requiring bright, high resolution, wide field-of-view visual systems.

A recent trend in the design of military flight simulator displays has been to use real (i.e., non-collimated) imagery that is presented within one meter of the observer. For example, the Display for Advanced Research and Training (DART) is an operational, real-image display developed at the Warfighter Training Research Division of the Air Force Research Laboratory (Thomas & Reining, 1990; Thomas & Geltmacher, 1993). Different versions of the DART use display screens located at either 0.94 or 0.61 m from the pilot. A concern with the use of these display systems is that

the observer's vergence and accommodation levels are greater when viewing real imagery at these distances than they are either in the real world or with collimated displays. Given that ocular vergence and accommodation can affect the perceived size of objects (cf. Sedgwick, 1986), it might be expected that the perceived size, and possibly the perceived motion, of objects displayed in a real-image simulator will not correspond to the physical object size and motion being simulated.

Misperceptions of the spatial and temporal relationships of objects simulated in a visual environment have important training implications. For example, fighter tasks such as low altitude terrain clearance maneuvers, defensive/offensive air combat maneuvers, and formation flight in a multi-ship environment all rely on an accurate perception of the size, distance, and motion of objects being simulated. If misperceptions occur during simulator training of these tasks, then negative training of both spatial and temporal relationships can result.

As a first step in assessing the changes in perceived size that may be associated with changes in ocular vergence, Wetzel, Pierce, and Geri (1996) measured the relative perceived size of objects viewed alternately on near (0.61 or 0.94 m) and far (8 m) displays. It was found that simple objects, displayed in an otherwise dark environment at either of the near viewing distances, appeared smaller than objects of the

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14. ABSTRACT There is some question as to whether non-collimated (i.e., real) imagery viewed at one meter or less provides sufficiently realistic visual cues to support out-the-window flight simulator training. As a first step toward answering this question, we have obtained perceived size and velocity estimates using both simple stimuli in a controlled laboratory setting and full simulator imagery in an apparatus consisting of optically combined collimated and real-image displays. In the size study it was found that real imagery appeared 15-30% smaller than collimated imagery. In the velocity studies, the laboratory data showed that the perceived velocity of real imagery was less than that of collimated imagery. No perceived velocity effects were found with the simulator imagery. Results support the position that for training tasks requiring accurate perception of spatial and temporal aspects of the simulated visual environment, misperceptions of size, but not velocity, need to be considered when real-image displays are used.				
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same angular size displayed at the far viewing distance. In the present study we have extended our investigation of size perception by using more realistic test stimuli, moving background textures, and distance cues more similar to those available in operational simulators. We have also performed both laboratory and simulator studies using moving stimuli to determine whether perceptual effects, analogous to those found for stimulus size, will also be found for stimulus motion.

METHOD

Perceived Size Study

Eight observers (five pilots and three non-pilots) participated in the size study. The flight experience of the pilots ranged from 1900 hr to 4500 hr with a mean of 2960 hr.

One stimulus image was viewed directly at a distance of 1.12 m (44 in) and thus served as the real image. The other image was reflected in a large spherical mirror and was effectively collimated. The two images were superimposed using a large glass beamsplitter. The sources of the real and collimated background images were an Ampro Model 3300 CRT projector and a Barco Model 801 CRT projector, respectively.

Stimuli were high-resolution aircraft targets on 35-mm slides that were superimposed onto the CRT projected background imagery in each channel. The background images were taken from a standard flight simulation database. Target types were F-15s flying in either formation flight (FF) at distances of 2500', 6000' looking up, 6000' looking down, and 9000', or a gun pass (GP) at distances of 1000' and 2000'. Thus, the independent variables in this study were Experience (pilots and non-pilots) and Target Type.

The size estimation trials began with a 5-sec presentation of the collimated test target and background image. That image was extinguished and the real-image test and background were presented for 5 sec. Using a response switch, observers then indicated whether the real test target appeared larger or smaller than the collimated test target. The size of the real test target was varied from trial to trial using a staircase technique. The staircase continued until at least ten response reversals were obtained. The average size of the real test target corresponding to these reversals was taken as the estimate of the percentage size difference for that staircase.

Perceived Velocity Studies

Four non-pilot observers participated in the laboratory-velocity study, where the stimuli were laterally moving arrays ($24^\circ \times 24^\circ$) of luminous dots in an otherwise dark field. The far (collimated) stimulus was located at a viewing distance of 5.5 m, and the near (real) stimulus was located at a viewing distance of either 0.5 or 1.2 m. Stimulus velocities of 6, 12, and 18 deg/sec were tested. The stimulus conditions were such that ocular vergence was the only identifiable cue as to whether the far or the near stimulus was being viewed. A double random staircase technique was used. In one staircase, the standard was the far stimulus; in the other, the standard was the near stimulus. For both staircases, presentation order of the standard and variable stimuli was randomized. On each trial, observers viewed the two stimuli sequentially and responded as to whether the second stimulus presented appeared to be moving faster or slower.

For the simulator-velocity study, the combined real- and collimated-display apparatus described above for the size study was again used. The viewing distance of the real image, however, was reduced to 0.84 m. Four non-pilot observers participated. Flight through the database was simulated at two altitudes (300' and 3000'), and two types of movement (forward and lateral) through the database were tested. The movement stimulus was a standard database, which at the 300' altitude displayed typical ground texture and numerous trees to provide salient cues to movement. At the 300' altitude, a velocity of 1200 knots was chosen to give an average velocity near the midrange of the velocities used in the laboratory study. At the 3000' altitude, a velocity of 1800 knots was used, which resulted in much lower terrain movement. In addition, the moving terrain at this altitude provided less salient depth cues. In this regard, the 3000' condition better approximated the motion stimuli used in the laboratory study than did the 300' condition. A double random staircase technique similar to the one described above for the laboratory-velocity study was used.

RESULTS

Perceived Size Study

The mean size estimates and standard errors of the mean for the combined data of the five pilots and three non-pilots are plotted in the right panel of Fig. 1. The figure shows the percentage difference in the perceived size of the real image relative to the collimated image that served as the standard. The filled

and open symbols correspond to data from the formation flight (FF) and gun-pass (GP) conditions, respectively. A positive difference in perceived size indicates that the real image was perceived to be smaller than the corresponding collimated image.

The percentage size differences were used as the dependent variables in a split-plot factorial Analysis of Variance [ANOVA] (Kirk, 1968, pp. 278, 279). The ANOVA showed a significant effect for Target Type, $F(5, 30) = 2.93, p < 0.03$. The main effect for Experience and the interaction were not significant ($p > 0.05$). A significant contrast effect was found for distance data sorted by flight type (FF vs. GP), $F(1, 30) = 7.68, p < 0.01$. Multiple *t*-tests were performed on all combinations of observer and target type to test whether the percentage size differences in the right panel of Fig. 1 were significantly different from zero. For each target type, at least seven of the eight observers showed significant differences ($p \leq .008$).

Perceived Velocity Studies

The mean velocity estimates and standard errors of the mean for the four observers tested in the laboratory study are shown in Fig. 2. The data are plotted as percentage differences between the near (real) and far (collimated) images, and are shown for the two near viewing distances (0.5 and 1.2 m). A *t*-value was computed for each of the data points shown in Fig. 2. Each of these points represents the mean of two staircase estimates for each of the four observers. Each point was significantly different from zero, $t(7) \geq 2.52, p < 0.05$. The significant deviations from zero for the 0.5 m and 1.2 m near conditions in Fig. 2 indicate that the perceived velocity of the near stimuli, to which the observers verged, was less than that of the far stimulus. We also tested the differences between the 0.5 m and 1.2 m data for each stimulus velocity, and all three differences were significant, $t(14) \geq 3.26, p < 0.01$.

Shown in Fig. 3 are the perceived velocity data averaged over the four observers from the simulator study. Each of these points represents the mean of two staircase estimates for each of the observers. For both flight altitudes (300' and 3000') and movement directions (forward and lateral) tested, there was no significant difference in the perceived velocity of the imagery presented on the real (0.84 m viewing distance) and collimated displays, $t(7) \leq 1.25, p > 0.20$.

DISCUSSION

The size perception data in the right panel of Fig. 1 indicate that when the same imagery is presented

on both real and collimated displays, its size may appear different. Differences in perceived size of 15-30% were found between the collimated and real imagery for formation flight (at distances of 2500', 6000', and 9000'). The analogous differences for the gun pass condition (at distances of 1000' and 2000') were 10-20%. Both the main effect for Target Type and the contrast between the formation flight (FF) and gun pass (GP) flight types were statistically significant. These results suggest either that there are significant differences in the cues available under these two flight conditions or that the absolute size of the judged aircraft is a relevant variable. It should be noted in this context that the GP aircraft were viewed from above and hence presented larger (in area) targets than the FF aircraft that were viewed from the side. Thus, more texture cues were visible on the GP aircraft, and several pilots claimed to use texture cues to judge distance (and hence size). On the other hand, more background texture cues were available in the FF condition, but only one pilot claimed to use terrain texture to judge distance, whereas three pilots explicitly stated that they did not believe that it was a reliable cue to object distance in the simulator.

Size perception data previously reported by Wetzel *et al.* (1996) are shown in the left panel of Fig. 1. These data have the same general magnitude and form as the data of the present study. This similarity suggests that any contextual (or other) cues added by the more realistic simulator imagery used in the present study did not overcome the simple convergence cue (i.e., the only cue available in the Wetzel *et al.* study) to target distance (and hence size).

The implications for perceived velocity, in the context of real versus collimated displays, are not as clear as for perceived size. We found a significant effect of viewing distance in our laboratory study for both near-viewing distances tested (Fig. 2). In the simulator study (Fig. 3), we found no significant effect for a near-viewing distance (0.84 m) intermediate between those used in the laboratory study. Although our data are not conclusive, we have found no evidence that misperceptions of velocity are a consequence of using real-image displays with flight simulator imagery.

One of the reasons for using collimated displays for flight simulation is that they provide a compelling impression of immersion in 3-D space. It is reasonable to expect that the way 3-D space is perceived will in turn affect perceived velocity through that space. Very salient monocular cues that also give the impression of immersion in 3-D space are provided by the moving imagery used to simulate low-altitude flight in high-

fidelity, real-image simulators. We therefore initially thought that the absence of a difference in perceived velocity between the real and collimated simulator displays was due to the real-image, monocular depth cues effectively substituting for those cues that provided the impression of 3-D space in the collimated display. In order to test this possibility we added the higher altitude (3000') flight condition, which provided much reduced monocular cues to depth. The data of Fig. 3 show, however, that even under this condition, no significant differences in perceived velocity were evident between the imagery presented on the collimated and real displays. Given the significant increase in the effect between the 1.2 m and the 0.5 m conditions in our laboratory-velocity study, it is possible that significant differences would have been found had we tested shorter viewing distances in the simulator. Recall, however, that we did get a significant velocity effect for the 1.2 m condition in the laboratory study (Fig. 2). It also should be noted that the distance tested in the simulator-velocity study (0.84 m) is shorter than that (i.e., 0.94 m) which resulted in significant differences in both our laboratory- and simulator-size studies (see Fig. 1).

Although statistically significant differences in perceived velocity were found for both the 0.5 m and 1.2 m near-viewing conditions in our laboratory study (see Fig. 2), the magnitudes of the effects suggest that only those at the 0.5 m viewing distance would be of practical significance to flight simulator training. There are real-image simulators with viewing distances as short as 0.6 m, but they are currently rare. It remains to be determined whether the visually compelling motion cues, such as optical flow and dynamic perspective changes, provided by high-fidelity simulators are sufficient to overcome the velocity effects reported here for simple laboratory stimuli and short viewing distances.

The perceived size experiments described here were undertaken to determine whether the well-known effects of size constancy might adversely affect training in flight simulators. The velocity studies followed under the assumption that velocity can be estimated as the time required for an object to move a given distance. The simulator task used in the velocity study is one that involves judgments of speed over terrain during low and medium altitude flight. We plan to extend this study to other low altitude tasks such as time to contact, and collision/ terrain avoidance. Despite great advances in image generators and visual displays, current simulators still do not provide the resolution required for training

many air-to-air and air-to-surface combat tasks. In view of this limitation, the size and velocity effects reported here may be of little practical importance for current generation displays. However, new display systems are currently being developed, which include both high-resolution insets, provided by superimposed CRT imagery, and full-field, high-resolution imagery provided by laser projectors. When these higher-resolution systems become available, perceptual effects related to those described here may become the limiting factor in providing realistic and effective flight simulator training using real-image displays.

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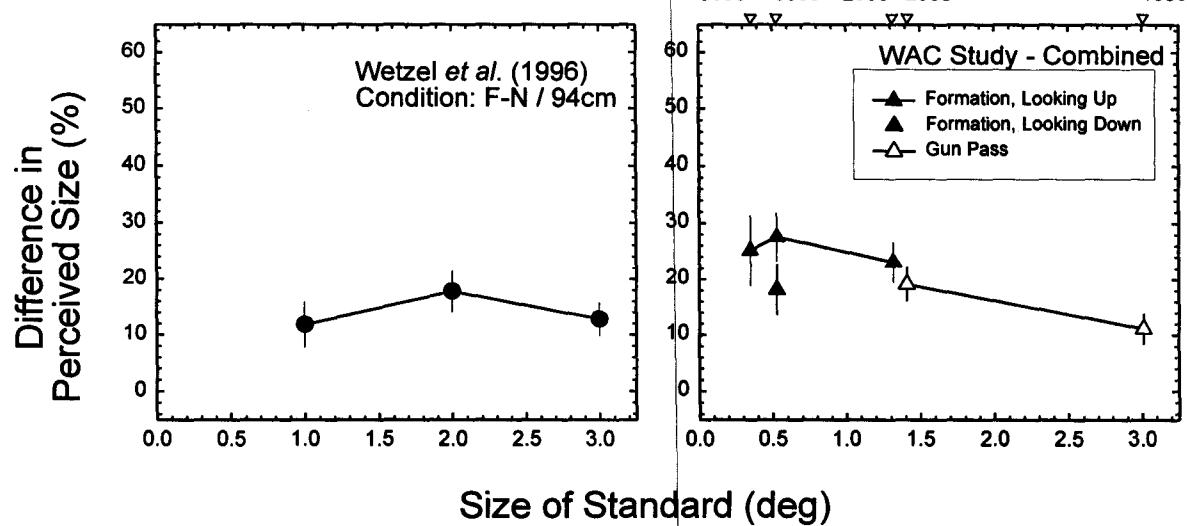


Fig. 1. Laboratory (upper left) and WAC (simulator) data on the difference in perceived size with viewing distance. There was no significant difference between the pilot and non-pilot data in the WAC study, and so the two sets of data have been combined.

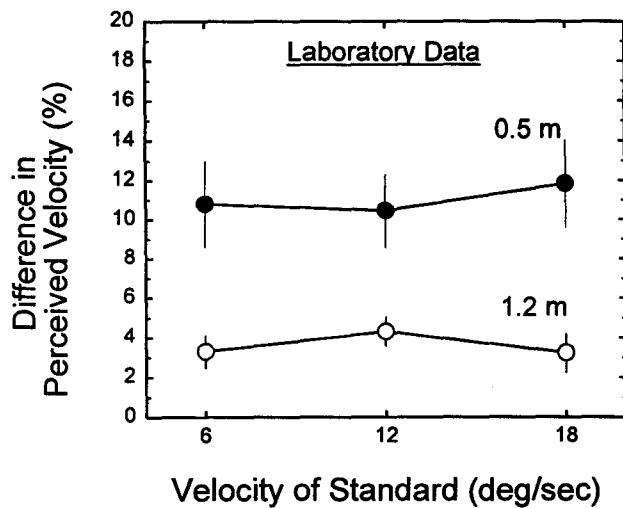


Fig. 2. Laboratory data on the difference in perceived lateral velocity between a far stimulus located at 5.5 m viewing distance and each of two near stimuli located at either 0.5 m or 1.2 m.

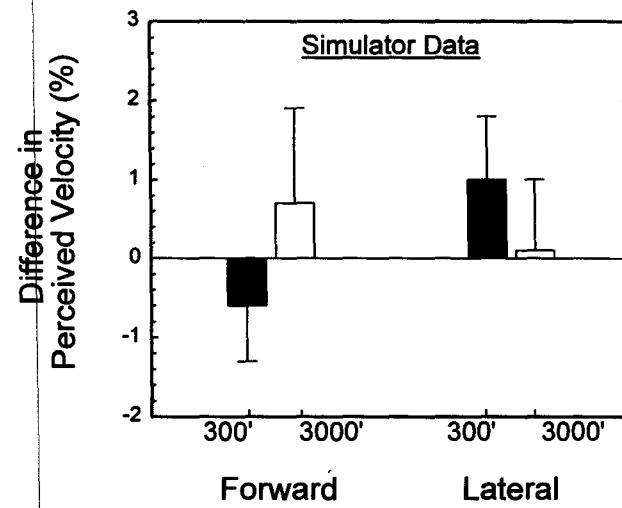


Fig. 3. Simulator data on the difference in perceived velocity between a far (collimated) image and a near (0.84 m) real image, for each of two flight altitudes (300' and 3000'), and each of two movement directions (forward and lateral).